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James L. Smith

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EQUILIBRIUM PATTERNS OF COMPETITION IN OCS LEASE SALES

James L. Smith

Center for Energy Policy Research
Massachusetts Institute of Technology

Abstract

An equilibrium model of bidding behavior is developed that accounts for observed fluctuations in the degree of competition to acquire offshore petroleum leases. As one might expect, such fluctuations are related to the heterogeneity of geological prospects that are offered for sale, with a relatively high degree of competition to acquire tracts of the highest quality. The equilibrium configuration of bids is also shown to reflect structural characteristics, such as capital market constraints, that may restrict competition in the lease auction. Empirical evidence is presented which tends to confirm our general theory of bidding equilibria, but which contradicts the popular notion that capital constraints have restricted competition in OCS lease sales. Policy implications are discussed in the concluding section.

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EQUILIBRIUM PATTERNS OF COMPETITION IN OCS LEASE SALES

1. Introduction

In this paper we develop an equilibrium analysis of bidding behavior that accounts for patterns of competition observed in Outer Continental Shelf (OCS) petroleum lease sales. As one would expect, the equilibrium configuration of bids that obtains in this market is related to the heterogeneity of geological prospects that are offered for sale; with a relatively large number of bids concentrated on tracts of the highest value. However, the equilibrium configuration may also reflect structural characteristics, such as capital market constraints, that restrict competition in the auction market. The influence of these factors on the configuration of bids is described below. We also examine some empirical evidence which tends to confirm our general theory of bidding equilibria, but contradicts the popular notion that capital constraints have restricted competition in OCS lease sales. Some policy implications of these results are discussed in the concluding section.

2. Relation to Previous Studies

A lease sale consists of the simultaneous letting of many individual tracts by the method of competitive bidding. Each participant in the sale is invited to submit bids for those tracts it desires. Petroleum development rights are subsequently awarded to the highest bidder. A common outcome of the auction is that many of the tracts receive few, if any, bids; while others are hotly contested by the auction participants. A uniform degree of competition for respective tracts is most unusual.

Several previous studies have suggested that the underlying quality or geological potential of an offered tract is a primary determinant of the number of competitors it will draw. For example, Gaskins and Teisberg [1976] explore a game-theoretic model that determines the winning bidder's profit as a function of the tract's inherent value and the number of bidders competing for it. They define and identify an equilibrium number of bidders by increasing the degree of competition for the tract until expected profit falls below the cost of preparing a bid. The bidding models of Rothkopf [1969] and Wilson [1976] may, in principle, be similarly manipulated to determine the number of bidders required to dissipate expected profit and forestall additional competition. Although these studies focus on the sale of a single tract, they suggest a useful method of characterizing the spatial distribution of bids when multiple tracts are offered, as discussed below.

When several tracts are offered simultaneously, a bidder will generally not be indifferent regarding the choice of specific tracts on which to enter bids. For example, a large and promising geological structure which underlies a shallow water tract may offer the potential for considerable profit and attract many bidders. However, we cannot expect less promising tracts to be neglected entirely, because alert firms would recognize that against no competition even lower quality properties can be acquired on a profitable basis. Thus, it is reasonable to expect a pattern of competition to develop that equilizes profit opportunities among all offered tracts and renders potential bidders indifferent regarding the tracts on which their bids are placed. A spatial distribution of bids that does not equalize profit opportunities cannot be in equilibrium since participating firms would have an incentive to redirect their bids.

3. Theoretical Framework

It is possible to define and describe equilibrium bidding patterns within the context of a formal model of the auction market. We assume that T distinct tracts are offered, and that these tracts constitute independent investment opportunities.[1] The t^{th} tract is characterized by its petroleum reserve volume, R_t, and associated net economic value, V_t. Although we will proceed as if V_t and R_t were known with certainty, they could be construed as anticipated or expected values without changing the nature of the results.

The number of competitors for the t^{th} tract is denoted by n_t, and the expected value of the winning bid by $B_t(n_t)$. The relation between these two variables could be determined from an explicit formulation of the appropriate bidding game, but rather than adopt any particular formulation we stipulate only that the expected winning bid increase as a proportion of tract value when the number of competitors grows:

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[1]The introduction of covariances would complicate the analysis considerably, without shedding additional light on the nature of the competitive equilibrating mechanism.

$$(1) \qquad B_t(n) = g(n) \cdot V_t \; ;$$

with: $g'(n) > 0$.

This formulation is consistent with the game-theoretical bidding models of Vickrey [1961] and Rothkopf [1969], but still restrictive in that it requires the winner's share of economic rent to be independent of the magnitude of the tract's value.[1]

Finally, we assume the participants in the auction to be equally well-informed and identical in their application of bidding strategies. Consequently, the probability that each of the n_t competitors will be declared the winner is precisely $1/n_t$.

The expected profit, Π_t, anticipated by a potential bidder on the t^{th} tract can now be written directly as a function of the hypothesized degree of competition to obtain it:

$$(2) \qquad \Pi_t(n_t) = \frac{V_t \cdot [1 - g(n_t)]}{n_t} \; ; \qquad t = 1, \ldots, T.$$

For a particular pattern of competition $(n_1, \ldots, n_T)$ to constitute an equilibrium among expected-profit maximizing firms, it must succeed in reducing the expected profit on each tract to a common value. Thus, competitive equilibrium requires, using Equation (2):

$$(3) \qquad \frac{n_i}{n_j} = \frac{V_i}{V_j} \cdot \frac{1 - g(n_i)}{1 - g(n_j)} \; ; \qquad \text{for all } i \text{ and } j.$$

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[1] It is possible to relax this restriction considerably without altering the nature of our results. For example, we could incorporate the "flinching" hypothesis, which states that, ceterus paribus, increases in tract value inspire less than proportionate increases in the value of the winning bid. The details of this are left aside.

The bidding pattern characterized by Equation (3) reveals the direct influence which heterogeneous tract values exert on the configuration of bids. It is apparent upon inspection that a pattern of uniform competition ($n_i = n_j$) will fail unless all offered tracts are of equal value, which is unlikely. In equilibrium, tracts of greater value must attract greater competition.

The equilibrium configuration of Equation (3) would not apply to the bids of firms who face constrained opportunities. In particular, if firms face capital constraints which limit the total dollar volume of bids tendered by each, then the equilibrium must be formulated not in terms of absolute profit potentials, but in terms of profit per dollar of the bidding budget expended on respective tracts, Π_t/B_t.[1] Thus, we require, using Equations (1) and (2);

$$\text{(4)} \qquad \frac{n_i}{n_j} = \frac{g(n_i)}{g(n_j)} \cdot \frac{1 - g(n_j)}{1 - g(n_i)} \; ; \qquad \text{for all i and j.}$$

Equation (4) portrays the configuration of bids that would obtain under a regime of budget-constrained bidding. A pattern of uniform competition is the only configuration that generally satisfies the equilibrium condition, in spite of the heterogeneity of offered tracts. This result is in sharp contrast to the pattern of unconstrained bidding behavior derived above.

Finally, we consider firms that operate subject to a physical, rather than financial, constraint. Specifically, we consider firms whose bidding activity is confined to a limited volume of petroleum reserves; for example, a firm that elects to tender bids on no more

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[1] This is analogous to the rate of return criterion applied in other capital budgeting problems.

than 50 million barrels of reserves. Such constraints have not been discussed in the literature, but they would apply to firms that maintain target reserve levels, or to those constrained by a limited geological and managerial staff available to appraise offshore prospects and formulate appropriate bids.

If bidders do face physical constraints of this type, we must again revise the equilibrium condition. Profit per unit of underlying reserves, Π_t/R_t, becomes the appropriate investment criterion; and Equation (3) must be rewritten as:

$$(5) \qquad \frac{n_i}{n_j} = \frac{V_i/R_i}{V_j/R_j} \cdot \frac{1 - g(n_i)}{1 - g(n_j)} \; ; \qquad \text{for all } i \text{ and } j.$$

Equation (5) describes the configuration of bids that would obtain under a regime of physically-constrained bidding. A pattern of uniform competition is extremely unlikely here, but perhaps somewhat more plausible than in the unconstrained bidding case. Such a pattern could now prevail if unit mineral rents (V_i/R_i) were constant over all tracts. However, the existence of pronounced economies of scale in reservoir development effectively rules out this possibility.

In general, the competitive disparities required to equilibrate profit opportunities among tracts are necessarily less dramatic than underlying disparities in tract values. This follows directly from Equations (3) - (5), each of which requires:

$$(6) \qquad 1 \leq \frac{n_i}{n_j} < \frac{V_i}{V_j} \, , \qquad \text{for } V_i > V_j.$$

Thus, a tract bearing twice as many reserves is generally expected to draw fewer than twice as many competitors. The extent to which competitive variations are damped in this fashion differs among the three behavioral specifications. A regime of budget-constrained bidding suppresses such fluctuations entirely (i.e., $n_i = n_j$). At the other extreme is unconstrained bidding, which generates the widest differences among tracts. Somewhere in between lies the case of bidding subject to physical constraints. These distinctive theoretical results provide a new basis for investigating the empirical validity of the alternative behavioral hypotheses.

4. Empirical Evidence

We now consider available evidence regarding the three hypothesized modes of bidding: financially constrained, physically constrained, and unconstrained. We specifically examine the correspondence between empirical patterns of competition and underlying variations in tract value to determine which behavioral model is most consistent with historical experience.

The hypothesis least consistent with recent history is that bidding has been subject to financial constraints. Whereas this hypothesis implies the absence of systematic variation in the degree of competition, the data clearly show the opposite. Recent analyses of the leasing market reveal that the degree of competition is highly correlated with virtually all measures of tract quality investigated. For example, a Geological Survey [1978] study of eight sales finds a statistically significant positive correlation between the number of bidders per tract and each of: (a) the probability that the tract attains some production, (b) the probability that the tract attains flush production, and (c) gross production revenue. A separate study by Gribbin et al [1979] shows that the simple correlation exceeds 90% between number of bidders per tract and each of: (a) speed of development, (b) the probability the tract will be drilled, and (c) the probability the tract will be productive. Additional corroborating evidence regarding the correlation between number of bidders and underlying reserve volumes is presented later in this section. The combined weight of this evidence would seem to establish that bidders are attracted to tracts of high quality and value. The hypothesis that bidders have been constrained by a lack of funds is therefore contradicted.

The two remaining hypotheses (physically constrained versus unconstrained bidding) are both consistent with the general tendency of the more valuable properties to foster greater competition. However, the hypothesis of unconstrained bidding predicts relatively wide variations in the degree of competition to acquire dissimilar tracts. We focus on this distinction to see which hypothesis provides a better account of actual fluctuations in the degree of competition.

To proceed, we must adopt a more specific model of the lease sale. First, we specify a particular valuation model for petroleum reserves, of the form:

$$(7) \qquad V_t = \alpha \cdot R_t^{\varepsilon} ; \qquad t = 1, \ldots, T.$$

Parameter ε is an index of scale economies in reserve development. Its value may be presumed to exceed unity since it is known that a greater deposit size enhances the net economic value of each barrel of reserves.

We further assume that the behavior of the winning bid relative to tract value, $g(n) = B(n)/V$, follows the relationship:

$$(8) \qquad g(n) = \frac{n - \gamma}{n} ;$$

... where γ represents an arbitrary constant.

Equation (8) represents the case where the force of competition causes the expected value of the winning bid ultimately to converge to the value of the tract.[1] The parameter γ determines the speed of this convergence.

Substituting from Equations (7) and (8) into (3), we can write explicitly the necessary condition for an unconstrained bidding equilibrium:

$$(9) \qquad \frac{n_i}{n_j} = \left(\frac{R_i}{R_j}\right)^{\varepsilon/2}; \qquad \text{for all } i \text{ and } j.$$

Similarly, the condition for a physically constrained bidding equilibrium becomes:

$$(10) \qquad \frac{n_i}{n_j} = \left(\frac{R_i}{R_j}\right)^{\frac{\varepsilon-1}{2}}; \qquad \text{for all } i \text{ and } j.$$

Equations (9) and (10) offer alternative explanations of competitive fluctuations in terms of underlying variations in the volume of petroleum reserves. The predicted amplitude of competitive fluctuations differs markedly between the two models, depending on the extent of scale economies. This difference provides an opportunity for empirical study. For example, if the degree of scale economies (ε) were specified, we could then identify the predicted amplitude of competitive fluctuations, and determine which model conforms more closely to actual experience. Conversely, we can use actual fluctuations to estimate the extent of economies of scale from the following equation:

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[1]This convergence property has been shown by Wilson [1976] to apply to a rather wide class of game-theoretic bidding models.

$$(11) \qquad \ln(n_i/n_j) = \hat{\beta}\cdot\ln(R_i/R_j).$$

In conjunction with the hypothesis of unconstrained bidding, [Equation (9)], Equation (11) provides an estimate of the scale parameter: $\hat{\varepsilon} = 2\hat{\beta}$. In conjunction with the constrained bidding hypothesis [Equation (10)], a larger estimate is implied: $\hat{\varepsilon} = 2\hat{\beta} + 1$. The plausibility of the alternative hypotheses may then be judged in terms of their respective implications regarding the magnitude of economies of scale, about which we do have some prior notions.

To implement this approach, we have estimated Equation (11) on the basis of data from two recent OCS sales. The data reporting number of bidders per tract (n_i) are taken from the U.S. Geological Survey [1978]. Estimates of the volume of reserves underlying each tract (R_i) have been provided to the author by a major U.S. oil company. These data reflect the corporate geologists' best estimates, as of the date of sale, of the recoverable reserves of each of 43 tracts let in OCS sale #35, and an additional 16 tracts let in OCS sale #37. Both sales were held during 1975.

The data from both sales indicate a significant positive correlation between the perceived volume of reserves and the number of competitors drawn to each tract. The simple correlation between the two variables is 0.32 in the case of sale #35, and 0.21 in the case of sale #37. However, it is the non-linear correlation expressed by Equation (11) that is of most interest. Estimates of the coefficient β and related estimates of ε derived from Equation (11) are reported in Table 1. The estimates were obtained by a conventional application of generalized least squares that is described in the appendix.

TABLE 1: ESTIMATES OF THE SCALE PARAMETER

	$\hat{\beta}$	Estimated returns to scale ($\hat{\varepsilon}$): Unconstrained	Estimated returns to scale ($\hat{\varepsilon}$): Constrained	
Sale #35:	0.24	0.48	1.48	
	(0.11)	(0.22)	(0.22)	(standard errors)
Sale #37:	0.37	0.74	1.74	
	(0.23)	(0.46)	(0.46)	(standard errors)

Notes: Parameter β is estimated from the equation: $\ln(n_i/n_j) = \beta \cdot \ln(R_i/R_j)$, as discussed in the appendix.
The return to scale implied by the unconstrained bidding hypothesis is determined from $\hat{\varepsilon} = 2 \cdot \hat{\beta}$.
The return to scale implied by the constrained bidding hypothesis is determined from $\hat{\varepsilon} = 2 \cdot \hat{\beta} + 1$.

The principal conclusion from Table 1 is that the hypothesis of unconstrained bidding is inconsistent with the phenomenon of increasing returns to scale, and therefore implausible. The implication of decreasing returns is supported at the 95% significance level in sale #35 ($\hat{\varepsilon}$ = 0.48); and again at the 70% level in sale #37 ($\hat{\varepsilon}$ = 0.74), where only 16 observations were available for analysis.

If we reinterpret the same data from the alternative point of view (i.e., constrained bidding), the conclusion is reversed: returns to scale are estimated to be 148% in sale #35 and 174% in sale #37. Scale economies of this magnitude are eminently plausible, at least regarding the development of offshore petroleum reserves; so the results in Table 1 must be said to favor the hypothesis that bidding is subject to physical constraints.

The apparent difference in scale economies which arises between the two sales (148% vs. 174%) is not in itself a cause for alarm. In fact, such a difference should have been expected since one sale (#37) consisted primarily of gas deposits and the other (#35) consisted primarily of oil. Regarding the difference between the two minerals, Mansvelt Beck and Wiig [1977, p. 90] have concluded that economies of scale are "much more pronounced" for gas fields than for oil fields, due to the nature of the transportation problem. Thus, the difference which appears between sales #35 and #37 is in the expected direction and actually increases our confidence in the validity of the model. It does appear that the only hypothesis consistent with available evidence is that firms individually pursue limited volumes of reserves, and therefore seek to maximize expected profit opportunities per unit of underlying reserves. Both alternative hypotheses (unconstrained bidding and budget-constrained bidding) are strongly contradicted by the data and must be rejected.

5. Conclusions

The empirical results presented above shed new light on an old question. For years policymakers have suspected capital barriers of restricting competition in OCS lease sales. Fear of capital barriers is perhaps the only convincing explanation that can be given for the continued toleration of joint bidding ventures, which alleviate the capital burdens placed on individual firms. Most recently, the Congress has amended the United States Code [1978] to require the Secretary of Energy to further reduce capital requirements by instituting new and fundamentally different leasing procedures designed to alleviate front-end capital expenditures (e.g., profit-share bidding, royalty bidding, sequential bidding).

Our results suggest that the main effect of these revisions in leasing procedure may be to address a problem that is largely non-existent by imposing new administrative and informational costs on both the government and industry.[1] This conclusion must be regarded as preliminary since our results, although fairly robust with respect to model specificaiton, are based on a small sample of data from only two OCS sales. Nevertheless, the results clearly invite further research

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[1] Incentive-compatible schemes based on royalty and profit-share bidding are remarkably more information intensive than the present form of bonus bidding, in contradiction to the House Conference Committee's stated objective of "limiting administrative burdens on government and industry" [1978, p. 92].

on the possibility that capital barriers are of less significance than the Congress has been led to believe.

More important than our empirical results is the conceptual notion that good reasons do exist for fluctuations in the degree of competition in OCS lease sales. Too often attention has been focused on tracts that draw relatively few (one or two) bidders, the implication being that this degree of competition is insufficient to return fair market value to the government. As we have demonstrated, however, tracts of relatively low quality will quite properly fail to inspire maximum competition, even in a market that is fully competitive. OCS sale #5 is a good example of this phenomenon. Each of the 23 tracts let in sale #5 drew exactly one bid, thus raising concern about the receipt of fair market value. Yet, after 21 years, none of the 23 tracts has produced any oil or gas. Limited competition will suffice when fair market value is zero. The reader should not think that such occurrences are uncommon; of the 388 one-bidder tracts let prior to 1970, only 26% have yielded any production. In contrast, 48% of the tracts drawing four or more bidders have yielded some production, as shown by Gribbin, et al [1979].

Because of the extreme heterogeneity of offshore tracts, it makes little sense to speak of the average degree of competition exhibited in OCS sales, and even less to adopt this measure as an explicit target of public policy. Yet, the average level of competition continues to receive the primary attention of policymakers. During its latest round of policymaking, the Congress was again distracted from extensive economic evidence that OCS lease sales have consistently returned fair market value to the government (see, for example, Mead, Sorenson and Jones [1976], and Erickson and Spann [1974]) by the observation that throughout the history of OCS leasing the average level of competition has remained at less than four bidders per tract. There is no doubt that a fundamental misinterpretation of the significance of this simple statistic motivated Congress' demand for schemes to increase the level of competition, and imparted a major new direction to U.S. leasing policy.

APPENDIX: THE ECONOMETRIC MODEL

Consistent with the discussion in the text, the presumed dependence of the degree of competition on tract quality can be written in logarithmic form:

$$\text{(A1)} \qquad \ln(n_i) = \ln[n_i(\underline{R})] + v_i\ , \qquad \text{for } i = 1, \ldots, T;$$

... where $\underline{R}$ denotes a vector comprising the reserve volumes of the T distinct tracts, $(R_1, \ldots, R_T)$; and the v_i are assumed to be independent and identically distributed, $N(0,\sigma^2)$.

The logarithmic differential in competition between tracts is determined by subtraction:

$$\text{(A2)} \qquad \ln(n_i) - \ln(n_j) = \ln[n_i(\underline{R})] - \ln[n_j(\underline{R})] + (v_i - v_j); \text{ for all } i \text{ and } j.$$

The appropriate functional form of Equation (A2) is derived from theoretical principles in section 4 of the text, giving:

$$\text{(A3)} \qquad \ln(n_i) - \ln(n_j) = \beta\cdot[\ln(R_i)-\ln(R_j)] + (v_i - v_j); \text{ for all } i \text{ and } j.$$

Equation (A3) is a suitable estimating equation for β, except that the residual covariance matrix is heteroscedastic and serially correlated. Generalized least squares could be applied, but the non-symmetry of the residual covariance matrix makes this procedure laborious.

An alternative estimating equation may be derived from Equation (A3) by summing over index j and dividing by the total number of tracts. This yields:

$$\text{(A4)} \qquad \ln(n_i) - \ln[G(n)] = \beta\cdot\{\ln(R_i) - \ln[G(R)]\} + (v_i-\bar{v});$$

$$\text{for } i = 1, \ldots, T;$$

... where $G(x)$ denotes the sample geometric mean of variable x, and $\bar{v}$ denotes the arithmetic mean of the v_i.

The residual covariance matrix of Equation (A4) is symmetric and of the form: $\sigma^2\cdot[I - \frac{\iota\iota'}{T}]$, where I denotes the TxT identity matrix and ι denotes the T-element column vector consisting entirely of ones. The parameter estimates reported in the text were obtained by applying the method of generalized least squares to Equation (A4).

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